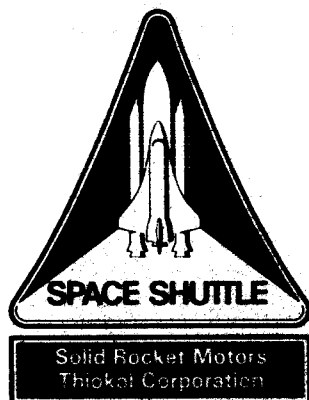


TWR-50290



Thiokol/Wasatch Installation Evaluation of the Redesigned Field Joint Protection System (Concepts 1 and 1C) Final Test Report

January 1990

Prepared for

**National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812**

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Thiokol/Wasatch Installation Evaluation of the
Redesigned Field Joint Protection System
(Concepts 1 and 1C)
Final Test Report

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ABSTRACT

Redesigned field joint protection system installations were performed between 12 and 20 Dec 1989 at Thiokol Corporation Static Test Bay T-18. The purpose of the installations was to develop the procedures and processing capability of the field joint protection system redesign Concept 1C, and to evaluate the use of three different adhesives for field joint protection system redesign Concept 1. The Concept 1 (double cork band design) configuration consists of two cork bands with K5NA ablation compound applied between them and to the bottom edge of the aft cork band. The aft cork band for the Concept 1 configuration is located over the joint pin retainer band. The Concept 1C (double cork band/K5NA design) configuration also consists of two cork bands with ablation compound applied between them, with the aft cork band located over the outer clevis leg transition area.

The steel strapping bands used for the Concept 1C cork band installations did not apply enough pressure to keep the cork butt joints pressed firmly against the case. The K5NA slumped during cure and became unbonded at several areas on the forward cork band bondline. Pull test results showed that pressure on the forward cork band may not have been adequate to result in a consistent bondline. A Concept 1C installation would last approximately 73.5 hr, compared to a Concept 1 installation which would last approximately 67 hr.

Personnel applying the adhesives for the Concept 1 adhesive comparison preferred the workability of the EC 2216 adhesive with Cab-O-Sil best, then the EA 934NA adhesive with Cab-O-Sil, and lastly the EA 934NA adhesive without filler. Visual inspection revealed bubbles in the cured EC 2216 adhesive. The EA 934NA adhesive with Cab-O-Sil bondline had a few small pits, and the EA 934NA adhesive bondline was void free. Cohesive cork failures in the pull tests indicated adequate adhesion for each adhesive.

Concept 1 of the redesigned field joint protection system proposals should be used on future redesigned solid rocket motors, and further development of the Concept 1C proposal should be discontinued. Concept 1 is recommended over Concept 1C because it is easier to process and verify and its K5NA volume is less likely to slump.

Potlife and cure time, as well as the mechanical and thermal properties of EA 934NA adhesive with Cab-O-Sil filler and EC 2216 adhesive with and without Cab-O-Sil filler, should be further evaluated to determine if they would be preferable to EA 934NA without Cab-O-Sil filler. Improving the requirements for ablation compound viscosity to prevent slumping should also be evaluated.

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ACRONYMS AND ABBREVIATIONS

EPDM	ethylene-propylene-diene monomer
FJPS	field joint protection system
KSC	Kennedy Space Center
LSOC	Lockheed Space Operations Company
min	minute
MSFC	Marshall Space Flight Center
RSRM	redesigned solid rocket motor
SRM	solid rocket motor

INTRODUCTION

This report documents the procedures, performance, and results obtained from the Thiokol Corporation/Wasatch redesigned field joint protection system (FJPS) installation evaluation. The evaluation was performed between 12 and 20 Dec 1989 at Thiokol Corporation Static Test Bay T-18. Testing was performed in accordance with ETP-0620, Evaluation of the New FJPS Closeout Concept Test Plan. The purpose of the installations was to develop the procedures and processing capability of the FJPS redesign Concept 1C, and to evaluate the use of three different adhesives for FJPS redesign Concept 1. The evaluation was accomplished jointly by Thiokol Corporation, Lockheed Space Operations Company (LSOC), Kennedy Space Center (KSC), and Marshall Space Flight Center (MSFC) personnel.

The FJPS is installed on redesigned solid rocket motor (RSRM) field joints to prevent rain intrusion into the joints and to maintain the joint temperature sensors between 85° and 122°F while the boosters are on the launch pad. The FJPS is being redesigned to reduce installation timelines at KSC and to simplify or eliminate installation processing problems related to the present design of an ethylene-propylene-diene-monomer (EPDM) moisture seal/extruded cork combination (Figure 1).

Several installation techniques were evaluated, and a preferred method of application was developed for the Concept 1C installation. Comparative installation timelines between Concepts 1 and 1C were also developed. (A complete Concept 1 installation was previously performed under ETP-0600; the results are published in TWR-50138.)

1.1 TEST ARTICLE DESCRIPTION

Concept 1 (double cork band design) of the redesigned FJPS proposals utilizes two cork bands with STW5-3183 ablation compound (K5NA) applied between them and to the bottom edge of the aft cork band (Figure 2). The cork bands are bonded over the joint pin retainer band area and over the joint temperature sensor area. For this evaluation, only the aft cork band was installed. The aft cork sections were machined to fit against the pin retainer band (nominal tolerance). Three types of adhesive (to bond the aft cork band) were evaluated: STW4-3218 adhesive (EA 934NA), EA 934NA with Cab-O-Sil filler (2.5 percent by weight), and an MSFC-recommended adhesive (3M Scotch-Weld Brand Epoxy Adhesive, EC 2216 B/A Gray) with Cab-O-Sil filler (3.0 percent by weight).

The Concept 1C configuration (double cork band/K5NA design) also consists of two cork bands with K5NA applied between them (Figure 3). The aft cork band location extends from the

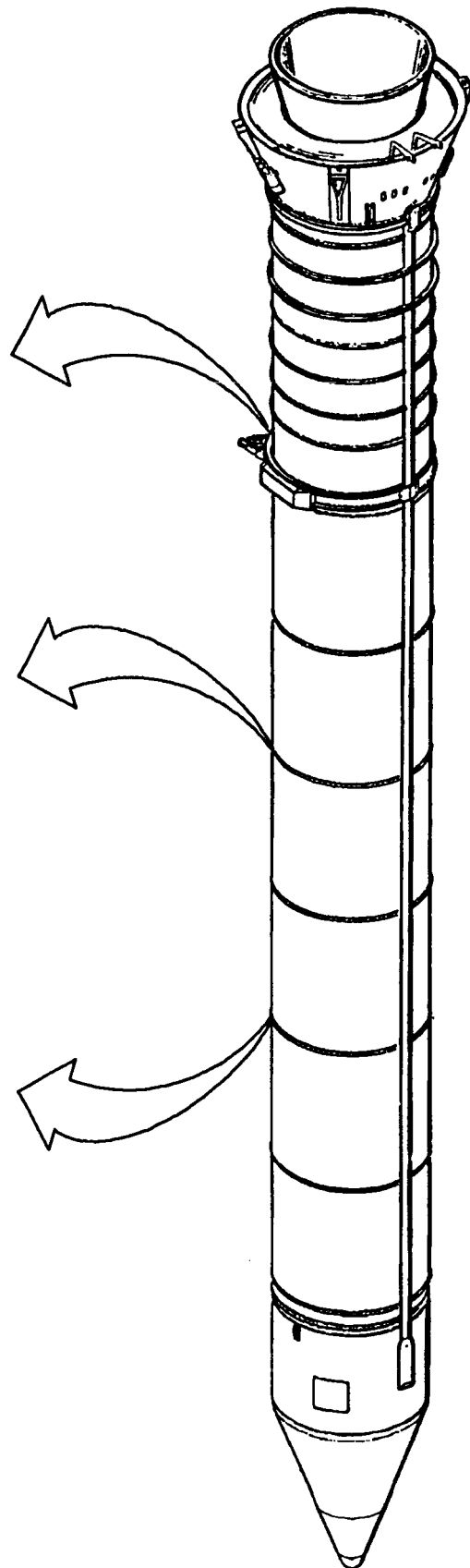
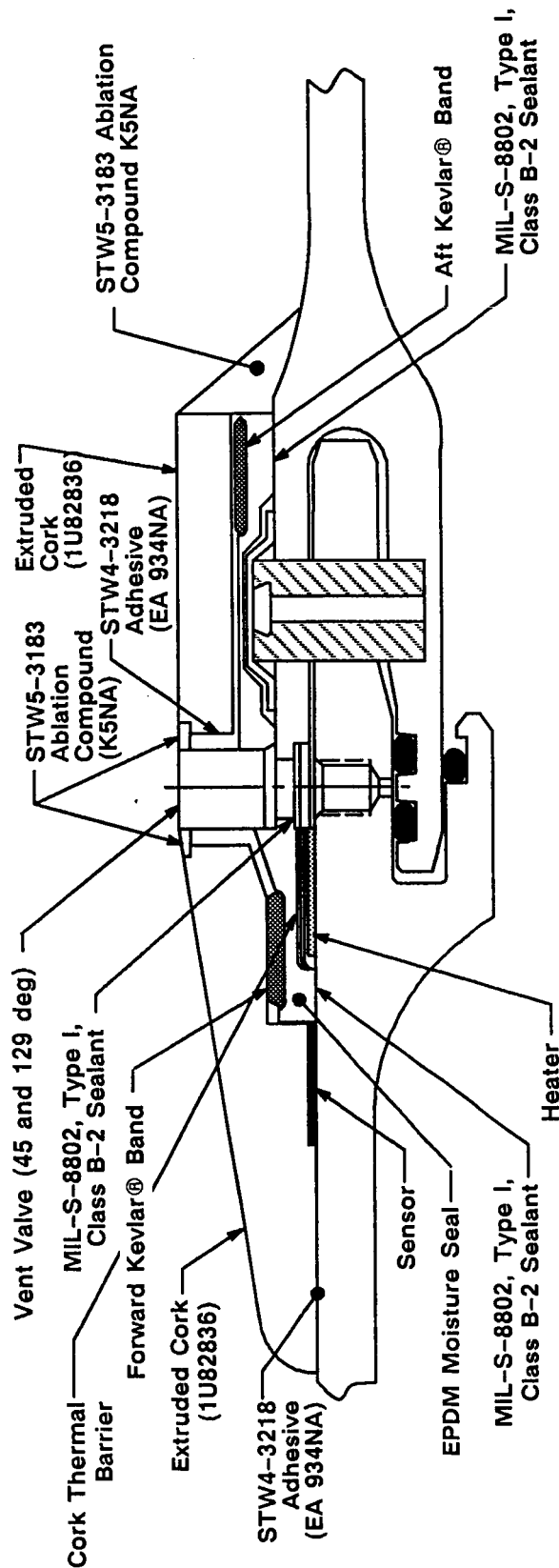
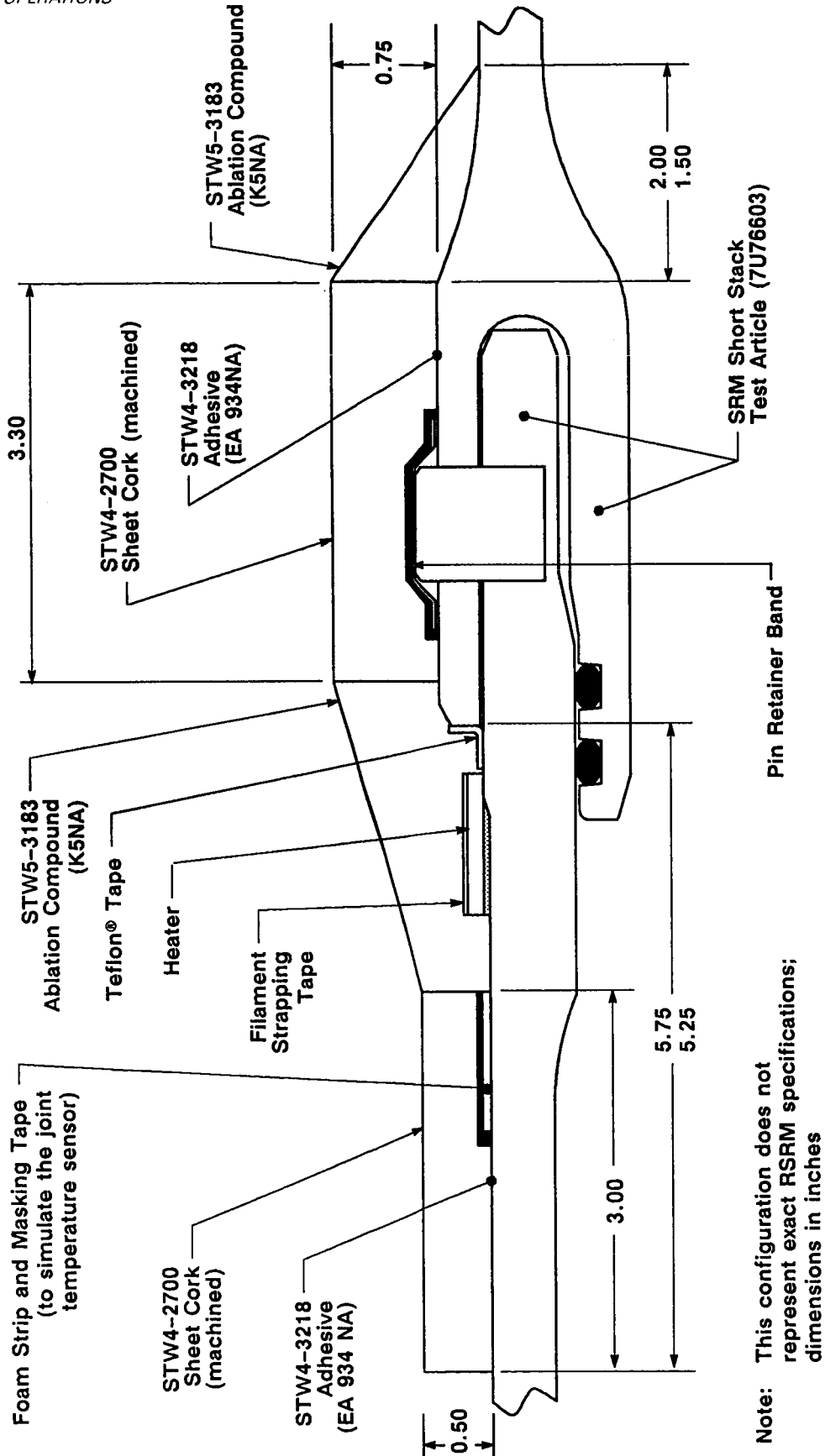


Figure 1. Current Design of the FJPS (EPDM moisture seal/extruded cork)

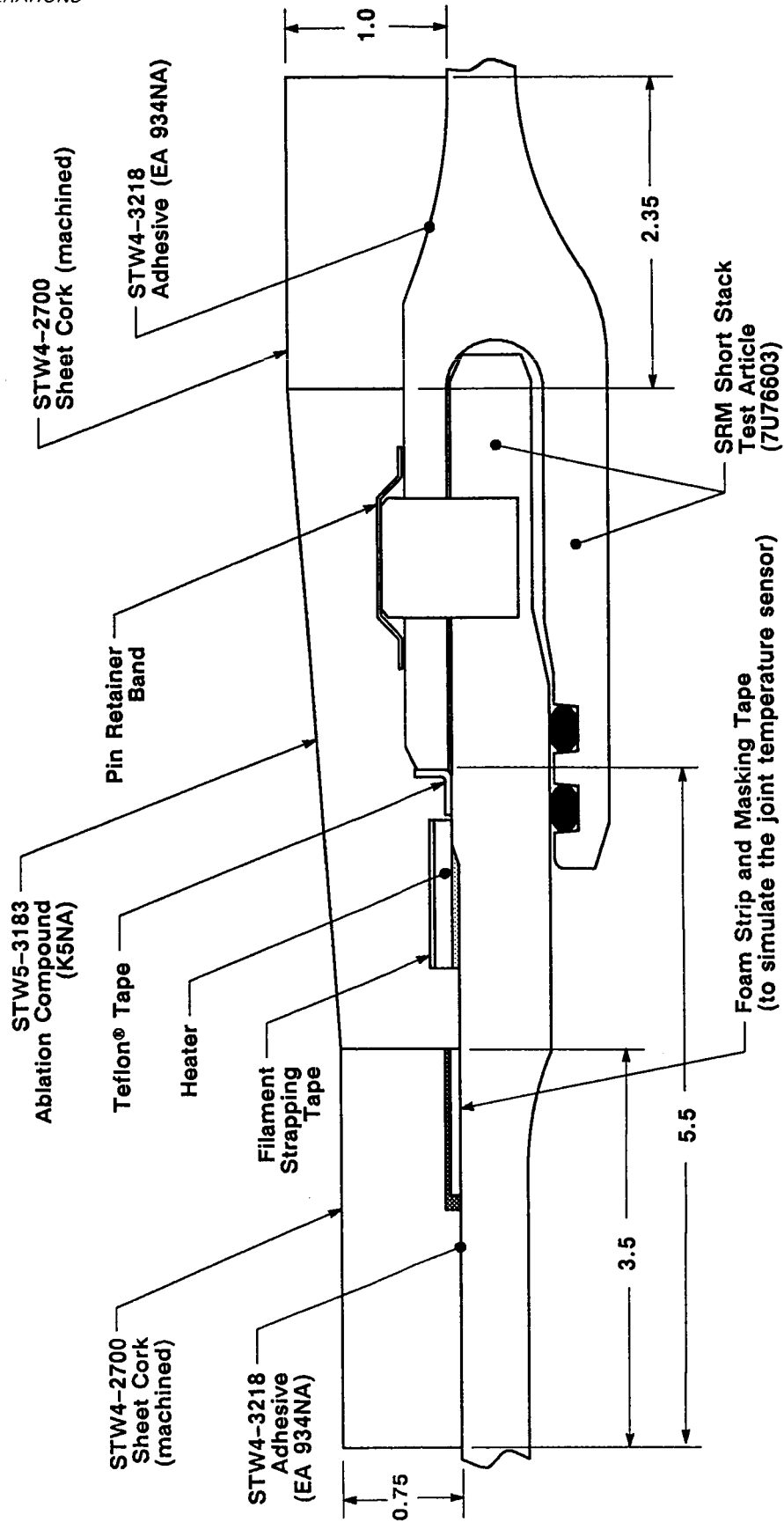
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Note: This configuration does not represent exact RSRM specifications; dimensions in inches

Figure 2. Concept 1 of the Redesigned FJPS—Installation Evaluation

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Note: This configuration does not represent exact RSRM specifications; dimensions in inches

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Figure 3. Concept 1C of the Redesigned FJPS—Installation Evaluation

outer clevis leg transition area to just aft of the pin retainer band. The forward cork band is located over the joint temperature sensor. EA 934NA adhesive was used to bond the cork bands.

Both proposals eliminate the vent valves, the vacuum bagging process, and the need for a separate moisture seal. Both concepts use a single Kevlar[®] strap to hold the heater in place as compared to the moisture seal/Kevlar[®] strap method of the current configuration. For this evaluation the heater was held in place with filament strapping tape. Specific dimensions of each concept were determined through structural and thermal analysis (TWR-50018 and TWR-50253).

The proposed FJPS configurations were installed on a mated solid rocket motor (SRM) short stack (7U76603) in the vertical (flight) position. (The outside surface contour of an SRM field joint is the same as the RSRM contour.) The assembly included the joint pins and pin retainer band. A foam strip was installed to simulate the joint temperature sensor. To prevent contamination, a layer of Teflon[®] tape was installed over the gap at the clevis/tang interface for each installation.

OBJECTIVES

The objectives of test plan ETP-0620 were to:

- A. Demonstrate the installation process for the redesigned FJPS.
- B. Define any cork band installation problems with the pin retainer band nominal dimensions.
- C. Determine if cracking, shrinking, or slumping occurs in the ablation compound (K5NA) after application.
- D. Evaluate the bondline void effects of steel strapping bands used to secure the cork during cure.
- E. Evaluate the cork band bondline that has been machined to nominal dimensions over the pin retainer band.
- F. Compare Concept 1C timelines to previously tested and current FJPS configurations.
- G. Evaluate the use of Cab-O-Sil in EA 934NA adhesive to reduce bondline voids.

EXECUTIVE SUMMARY

3.1 SUMMARY

This section contains an executive summary of the key results from test data evaluation and post-test inspection. Additional information and details can be found in Section 6, Results and Discussion.

Redesigned FJPS Concepts 1 and 1C were partially installed on the vertical short stack test article per drawing TUL-16825. Bondline surfaces were abraded, blacklight inspected, and solvent cleaned as necessary prior to each installation. Portions of each installation were installed over Teflon[®] tape to aid in removal and bondline inspection.

The Concept 1C configuration was installed first (Figure 3). The forward and aft cork sections were installed and held in place with steel strapping bands. The pressure applied by the steel strapping bands was not enough to keep the cork butt joints pressed firmly against the case. As a result, plastic shims were placed between the steel and cork bands over the butt joints. With the use of plastic shims, adhesive squeezeout occurred across the entire cork/case bondline. During K5NA application, it was difficult to keep the K5NA from slumping and separating from the forward cork band. The K5NA slumped during cure and became unbonded at several areas on the forward cork band bondline. Bondline bubble voids occurred in the case-Teflon[®] tape/aft cork band bondline. The forward cork band/case-Teflon[®] tape bondline was smooth and uniform. The presence of cork/case adhesive bondline voids could have been caused by separations between the cork and case during the installation process. Pull test results showed that pressure on the forward cork band may not have been adequate to result in a consistent bondline.

The installation of Concept 1 aft cork band sections was then performed, to compare three adhesives (Figure 2). The three adhesives evaluated were: EA 934NA adhesive, EA 934NA adhesive with Cab-O-Sil filler (2.5 percent by weight), and EC 2216 adhesive with Cab-O-Sil filler (3.0 percent by weight). Personnel applying the adhesives preferred the workability of the EC 2216 adhesive with Cab-O-Sil best, then the EA 934NA adhesive with Cab-O-Sil, and lastly the EA 934NA adhesive without filler. Removal of the cork sections that were installed over Teflon[®] tape revealed bubbles in the cured EC 2216 adhesive. The EA 934NA adhesive with Cab-O-Sil bondline had a few small pits. The EA 934NA adhesive bondline had no visible voids and was thinner than the other two adhesive bondlines. Pull test results indicated that the pin retainer band surface may have been contaminated for the EA 934NA adhesive installation. Cohesive cork failures in the other pull tests indicated adequate adhesion for each adhesive.

3.2 CONCLUSIONS

Listed below are the conclusions as they relate specifically to the objectives. Additional information about the conclusions can be found in Section 6, Results and Discussion.

<u>Objective</u>	<u>Conclusion</u>
A. Demonstrate the installation process for the redesigned FJPS.	<p>The Concept 1C (double cork band/K5NA design) installation was demonstrated and a preferred method of application was developed. The clevis outer leg transition area of the SRM short stack test article had an axial variation of approximately 0.5 inch. This variation was not as extreme as on some case segments; therefore, this installation did not represent a worst case.</p> <p>Installation of a Concept 1 (double cork band design) aft cork band with three different types of adhesive was also demonstrated. The three adhesives evaluated were: EA 934NA adhesive, EA 934NA adhesive with Cab-O-Sil filler (2.5 percent by weight), and EC 2216 adhesive with Cab-O-Sil filler (3.0 percent by weight). A complete Concept 1 installation was previously performed under ETP-0600, and the results are published in TWR-50138.</p>
B. Define any cork band installation problems with the pin retainer band nominal dimensions.	<p>No installation problems were encountered during installation of the Concept 1 aft cork band (machined to nominal pin retainer band dimensions). The pin retainer band was installed on the short stack test article to approximately nominal dimensions. It may be necessary during future installations to carve the cork to fit occasional pin retainer band protuberances.</p>

Objective

- C. Determined if cracking, shrinking, or slumping occurs in the ablation compound (K5NA) after application.

Conclusion

During K5NA application on the Concept 1C installation, it was difficult to keep the K5NA from slumping and separating from the forward cork band.

The K5NA slumped during cure and became unbonded at several areas on the forward cork band bondline. The more viscous the K5NA batch, the less slumping occurred. The maximum forward cork band/K5NA unbond depth was 3/16 inch. No visible cracking or shrinking occurred in the K5NA.

Improving the requirements for ablation compound viscosity should be evaluated. Ablation compound viscosity is dependant on cork particle size for a given weight. The current requirement for ablation compound, STW5-3183, allows for a variation in cork particle size that results in unusable mixes.

Objective

- D. Evaluate the bondline void effects of steel strapping bands used to secure the cork during cure.

Conclusion

The thicker cork bands of the Concept 1C configuration, as compared to the Concept 1 configuration, were more difficult to secure with the steel strapping bands. The pressure applied by the steel strapping bands was not enough to keep the aft and forward cork butt joints pressed firmly against the case. As a result, plastic shims were placed between the steel and cork bands over the butt joints. With the use of plastic shims, adhesive squeezeout occurred across the entire cork/case bondline.

A postcure removal/inspection revealed bondline bubble voids in the case-Teflon[®] tape/aft cork band bondline for the Concept 1C installation. These most likely occurred because the cork band slid aft during cure, after the cork guide was removed. The forward cork band/case-Teflon[®] tape bondline was smooth form.

The presence of cork/case adhesive bondline voids, bubbles, and pits could have been caused by separations between the cork and case during the installation process. After the adhesive-coated cork was initially fitted against the case, it may have separated at the cork section ends and other areas prior to tightening of the steel strapping bands.

Objective

- E. Evaluate the cork band bondline that has been machined to nominal dimensions over the pin retainer band.

- F. Compare Concept 1C timelines to previously tested and current FJPS configurations.

Conclusion

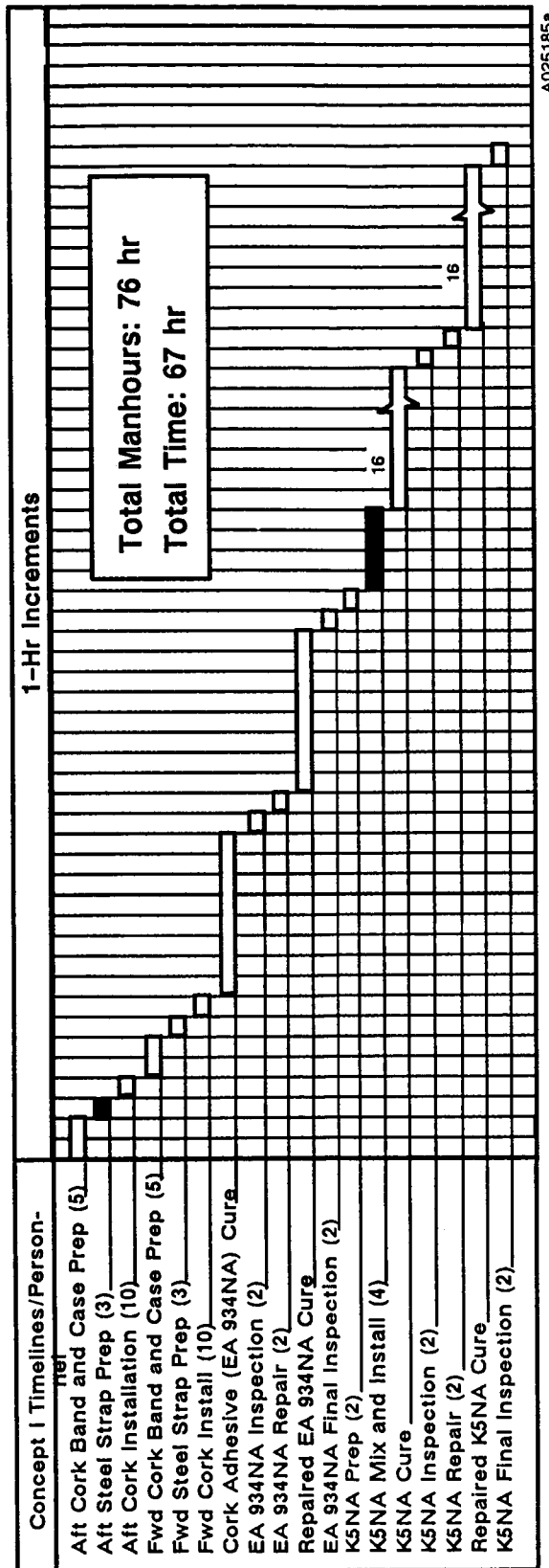
Removal of the Concept 1 aft cork sections that were installed over Teflon[®] tape revealed bubbles in the cured EC 2216 adhesive. The EA 934NA adhesive with Cab-O-Sil bondline had a few small pits. The EA 934NA adhesive bondline had no visible voids and was thinner than the other two adhesive bondlines.

Cork pull tests were performed over each adhesive for cork sections that were installed directly over the case. Two of the seven pull tests performed over the EA 934NA adhesives failed at the cork/case adhesive bondline, indicating that the pin retainer band surface may have been contaminated during installation. Cohesive cork failures in the other pull tests indicate adequate adhesion for each adhesive.

A Concept 1 installation would last approximately 67 hr, and a Concept 1C installation would last approximately 73.5 hr. The Concept 1C configuration requires a longer processing time because of the aft cork guide installation and larger volume of K5NA, which promotes slumping (depending on the viscosity of the K5NA mix). Both proposed configurations are capable of reducing the current FJPS installation time (144 hr per joint) by the design goal of 50 percent. Timelines are shown in Tables 1 and 2.

The postflight disassembly/removal of each proposed configuration would be identical.

Table 1. Redesigned FJPS Timelines (Concept 1—double cork band design)

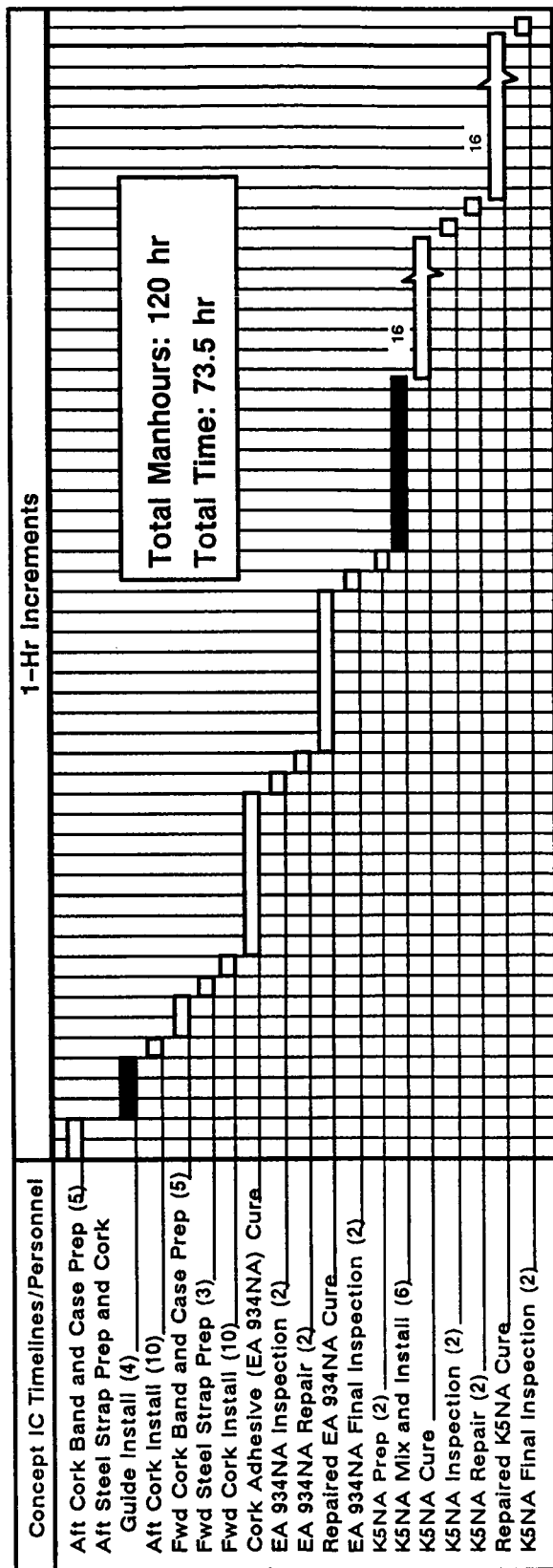


Based on testing under ETP-0600 and ETP-0620

Note: The main difference between the two configurations is that Concept 1C requires an additional 2 hr to install the aft cork band guide and also requires an additional 4-1/2 hr to install the K5NA ablation compound

K5NA installation times are based on application of one batch after another with one quality control person. Each batch has a 30-minute pot life. Eight batches are required for Concept 1; 17 batches are required for Concept 1C

Table 2. Redesigned FJPS Timelines (Concept 1C--double cork band/K5NA design)



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Based on testing under ETP-0600 and ETP-0620

Note: The main difference between the two configurations is that Concept 1C requires an additional 2 hr to install the aft cork band guide and also requires an additional 4-1/2 hr to install the K5NA ablation compound

K5NA installation times are based on application of one batch after another with one quality control person. Each batch has a 30-minute pot life. Eight batches are required for Concept 1; 17 batches are required for Concept 1C

<u>Objective</u>	<u>Conclusion</u>
G. Evaluate the use of Cab-O-Sil in EA 934NA adhesive to reduce bondline voids.	Personnel applying the adhesives preferred the workability of EA 934NA adhesive with Cab-O-Sil filler (2.5 percent by weight) over EA 934NA adhesive without filler. Removal of the Concept 1 aft cork band sections that were installed over the Teflon [®] tape revealed a few small pits in the EA 934NA adhesive with Cab-O-Sil bondline. The EA 934NA adhesive bondline had no visible voids and was thinner than the EA 934NA adhesive with Cab-O-Sil bondline. It was therefore concluded that adding Cab-O-Sil filler to EA 934NA adhesive does not reduce bondline voids.

3.3 RECOMMENDATIONS

Based on the results of this test, the following recommendations can be made:

- a. Concept 1 of the redesigned FJPS proposals should be used on future RSRMs, and further development of the Concept 1C proposal should be discontinued. The Concept 1 configuration is recommended over the Concept 1C configuration because it is easier to process and verify, and its K5NA volume is less likely to slump.
- b. A Concept 1 installation should be demonstrated at KSC using LSOC planning. The installation should be performed by space shuttle processing contractor personnel and should include Quality Assurance approval, just as if the installation were for a flight RSRM. Timelines and accessibility to perform the work at the Vehicle Assembly Building should be demonstrated.
- c. Potlife and cure time, as well as the mechanical and thermal properties of EA 934NA adhesive with Cab-O-Sil filler, and EC 2216 adhesive with and without Cab-O-Sil filler should be further evaluated to determine if they would be preferable to EA 934NA without Cab-O-Sil filler.
- d. Improving the requirements for ablation compound viscosity, to prevent the slumping that occurred during the Concept 1C installation, should also be evaluated. Ablation compound viscosity is dependant on cork particle size for a given weight. The current requirement for ablation compound, STW5-3183, allows for a variation in cork particle size that results in unusable mixes.

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- e. The presence of cork/case adhesive bondline voids, bubbles, and pits could have been caused by separations between the cork and case during the installation process. After the adhesive-coated cork was initially fitted against the case, it may have separated at the cork section ends and other areas prior to the tightening of the steel strapping bands. In future installations, firm pressure must be maintained against the cork after it has been positioned on the case.
- f. Methods of pin retainer band surface bondline preparation should be investigated. Hand abrading the surface should be compared to grit blasting and other methods to determine which method results in a better adhesive bondline and which method is easiest to process. An adhesion-promoting primer coating should also be evaluated.

4

INSTRUMENTATION

A hydrothermograph was used to measure the test bay ambient temperature during this evaluation.

5

PHOTOGRAPHY

Still color photographs of the two redesigned FJPS configurations were taken throughout each assembly and disassembly process. Copies of the photographs (series No. 114769, 114775, 114795, 114873) are available from the Thiokol Corporation Photographic Services Department.

RESULTS AND DISCUSSION

6.1 SHORT STACK TEST ARTICLE ASSEMBLY

The test article consisted of a mated SRM short stack (7U76603) in the vertical (flight) position. (The outside surface contour of an SRM field joint is the same as the RSRM contour.) The assembly included the joint pins and pin retainer band. Approximately 40 percent of the case bondline surface was unpainted. A joint heater was installed and held in place with 1-in.-wide filament strapping tape. A foam strip was installed during the Concept 1C installation to simulate the joint temperature sensor. For each installation, a layer of Teflon[®] tape was installed over the gap at the clevis/tang interface to prevent joint contamination.

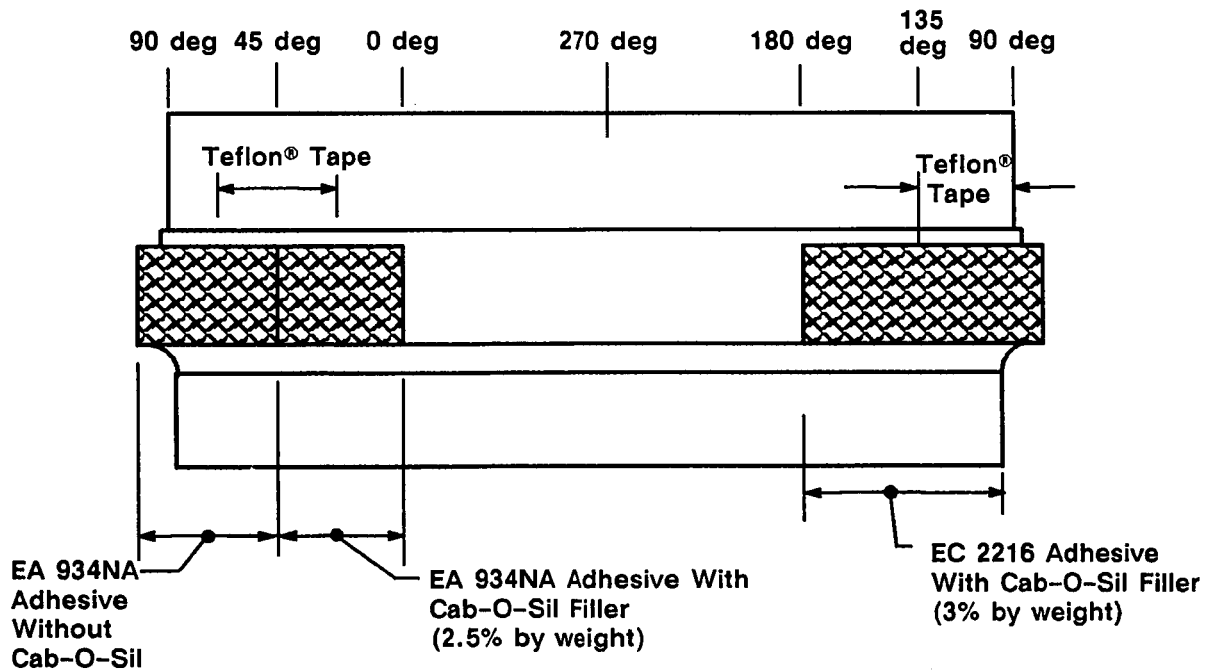
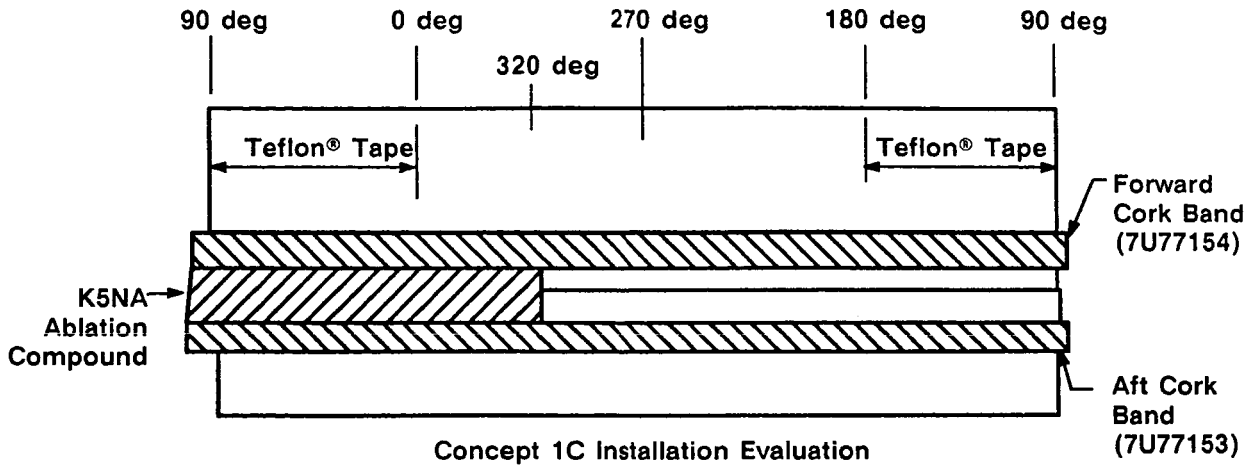
6.2 CONCEPT 1C INSTALLATION EVALUATION

The Concept 1C (double cork band/K5NA design) installation evaluation demonstrated the redesigned FJPS configuration, which consists of two cork bands with K5NA applied between them (Figure 3). The assembly was installed following the configuration of drawing TUL-16825. The 4-ft-long aft sheet cork sections were machined to fit the contour of the outer clevis leg transition area. The 4-ft-long forward sheet cork sections were machined to fit directly over the joint temperature sensor. The cork bands of the Concept 1C configuration were installed around the entire joint, and the K5NA was installed over 130 deg only (Figure 4).

Installation Preparation. A 180-deg section of the case bondline area was covered with Teflon[®] tape, the rest was prepared for a direct bondline to the case. The Teflon[®] tape; was installed to aid the removal/inspection of the bondline and to prevent contamination of the joint for use in further testing. The case surface was solvent cleaned prior to installation of the Teflon[®] tape. An adhesive-coated foam strip was installed to simulate the joint temperature sensor. Areas of the bondline surface that were not covered with Teflon[®] tape were abraded. After the joint was cleaned, the three steel strapping bands used to apply pressure to the cork strips were taped to the case (one steel strapping band was used for the aft cork band, and the other two steel strapping bands were used for the forward cork band). The bondline surface was black light inspected for contamination and solvent cleaned prior to the installation of each cork band.

6.2.1 Concept 1C Aft Cork Band

Installation Preparation. A 0.25-in.-thick band of sheet cork was strapped to the case to act as a guide for the aft cork band during installation. Teflon[®] tape was applied to the outer surface of each cork section 0.125-in. from the bondline edges. This provided stress relief between the cork and the steel strapping bands and kept the outer cork surface from being contaminated by



Concept 1 Adhesive Evaluation—Aft Cork Band (7U77128-01)

Figure 4. Concept 1 and 1C Installation Flat Pattern

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adhesive. The bonding surfaces of each cork section were then lightly abraded and solvent cleaned. The aft cork sections were then dry fitted, taped in place, and numbered.

Installation. The cork was removed from the case and placed on a clean table. EA 934NA adhesive was then mixed and applied to the cork bonding surface. A layer of adhesive was also applied to the case bonding surface. The cork sections were then installed and held in place with one steel strapping band, located over the center of the cork band. Tightening of the steel strapping band was performed in the systems tunnel area (Figure 5). Cork blocks were placed between the case and the steel strapping band in the systems tunnel area, assuring that uniform pressure was applied to the cork band. Band tensioning tool pressure was started at 10 psi, and then increased to 30 psi in 5-psi increments. After the 30-psi tool pressure was achieved, the steel strapping band was tapped with a rawhide mallet for 2 min to relieve localized tension. The tool was then retightened to 30 psi. The 30-psi tool pressure corresponded to approximately 700-lb tension in the steel strapping band. By analysis, approximately 10 lbf was applied to the cork 180 deg away from the band tensioning tool and approximately 12 lbf was applied to the cork at the band tensioning tool (refer to the appendix for the step-by-step analysis).

The pressure applied by the steel strapping band was not enough to keep the aft cork butt joints pressed firmly against the case. As a result, plastic shims were placed between the steel and cork bands over the butt joints (Figure 6). With the use of plastic shims, adhesive squeezeout occurred across the entire cork/case bondline. The following changes may have improved the aft cork band installation:

- A. Using two steel strapping bands or one wider steel strapping band.
- B. Tensioning the steel strapping band(s) at more than one location.
- C. Using sections of cork that are longer than 4 ft to reduce the amount of butt-joint bondline separations.

Installation Temperature/Potlife. The test bay ambient temperature varied between 40° and 55°F during the installation. The adhesive kits were warmed by the bay heater prior to being mixed. The potlife of EA 934NA adhesive varies with temperature: at 60°F, potlife is 98 min; at 90°F, potlife is 46 min (STW7-3631, Revision B). KSC does not have an application temperature range for EA 934NA. Because the installation was for evaluation only, it was decided that applying the adhesive below the current Thiokol-specified minimum temperature was acceptable.

Timelines/Personnel/Material. Three to five persons prepared the bonding surface over approximately 3 hr. Installation lasted 36 min from the beginning of adhesive mix until the strapping process was complete. The installation required 10 people. Four 1-qt kits of adhesive were used to bond the aft cork band.



Figure 5. Concept 1C Forward Cork Band--Steel Strapping Band Tensioning Processes

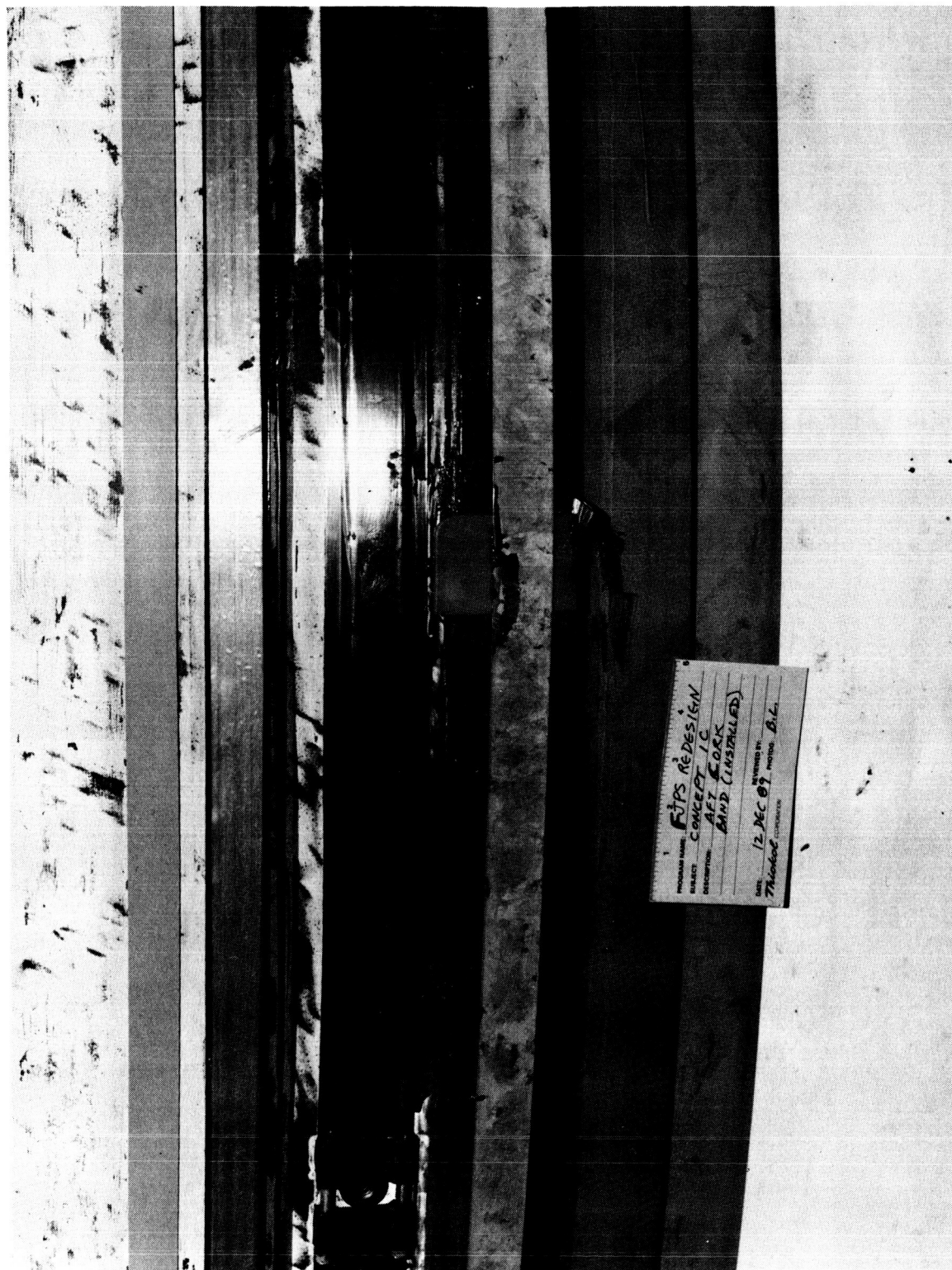


Figure 6. Concept 1C Aft Cork Band--Plastic Shim at Cork Butt Joint

6.2.2 Concept 1C Forward Cork Band

The forward cork band installation procedures were similar to the installation procedures for the aft cork band. Accurate fitting of the forward cork band over the foam strip (simulating the joint temperature sensor) was difficult; a guide for the top of the forward cork band would have made the installation easier. Since the two steel strapping bands had to go over the systems tunnel floor plates, cork blocks were placed between the sheet cork and raised steel strapping bands; this assured pressure on the sheet cork bonded near the systems tunnel. The cork butt joints were not firmly pressed against the case, and again, plastic shims were used to force the cork against the case.

The test bay ambient temperature varied between 40° and 55°F during the installation. Total installation time from the start of the first mix of EA 934NA was 38 min. Four 1-qt kits of adhesive were used to bond the forward cork band. Again, 10 persons installed the cork band.

6.2.3 Concept 1C K5NA Application

Installation/Material. Installation of the K5NA began 4 hr after the completion of cork installation. The three steel strapping bands were removed during the K5NA preparation process. Masking tape was applied to the top edges of the cork bands near the K5NA bondline for removal after the K5NA was installed. All of the case/cork/Teflon[®] tape bondline surfaces were wetted with a thin coat of K5NA just prior to the application of large amounts of K5NA. The preferred application method consisted of one person firmly applying K5NA to the desired area, another person sculpting the surface with a plastic spatula or a piece of Teflon[®]-taped cork, and a third person finishing the surface with a small Teflon[®]-coated rolling pin (Figure 7). The rolling pin was applied directly to the K5NA surface and was frequently cleaned with solvent. Most of the K5NA surface was covered with antistatic plastic film during the rolling pin process and during cure.

During K5NA application, it was difficult to keep the K5NA from slumping and separating from the forward cork band. Six batches of K5NA, all from the same lot, were installed over the 130-deg area. Only one of the six batches of K5NA had the proper viscosity; the other five mixes were too thin and thus difficult to apply. Current requirements for ablation compound allow extreme variation in cork particle volume density versus weight.

The sheet cork/K5NA interface required special attention during application. This bondline, particularly when cork was forward of the K5NA, tended to separate if extra pressure was not applied to the K5NA during application.

Installation Temperature/Timelines/Personnel. Room and case surface temperatures varied between 50° and 60°F during application. Cure temperature varied between 50° and 75°F during the 23 hr of cure. The installation was performed in just over 3 hr with an average of three



Figure 7. Concept 1C--Ablation Compound Installation

persons. Each batch of K5NA was applied within the currently specified 30-min potlife (at least two people were required to apply a batch within the potlife).

A complete Concept 1C installation at KSC would require approximately 73.5 hr (Table 2).

6.2.4 Concept 1C Postcure Inspection

Inspection. The K5NA slumped during cure and became unbonded at several areas on the forward cork band bondline. The more viscous the K5NA batch, the less slumping occurred. The maximum forward cork band/K5NA unbond depth was 3/16 inch. No visible cracking or shrinking occurred in the K5NA.

In several areas the final layer of plastic film was left on the K5NA surface until the K5NA could partially cure for at least 8 hr. Leaving the film on caused resin to rise to the surface (which may aid in moisture protection) and resulted in a very smooth, glossy K5NA surface. Where plastic film was removed prior to the K5NA cure, a more abrasive surface resulted.

The section that was applied over Teflon[®] tape was removed 23 hr after the completion of the K5NA application. The case-Teflon[®] tape/K5NA bondline was smooth and uniform.

Bondline bubble voids occurred in the case-Teflon[®] tape/aft cork band bondline (Figure 8). These most likely occurred because the cork band slid aft during cure after the cork guide was removed. During future installations, the aft cork guide should remain in place until the aft cork has cured. The largest of the voids was approximately 3.0 by 0.5 by 0.0625 inches. The forward cork band/case-Teflon[®] tape bondline was smooth and uniform. The presence of cork/case adhesive bondline voids could have been caused by separations between the cork and case during the installation process. After the adhesive-coated cork was initially fitted against the case, it may have separated at the cork section ends and other areas prior to the tightening of the steel strapping bands.

Pull Testing. Six days after K5NA application, pull testing was performed to determine bondline integrity on the portion of the forward cork band that was installed directly to the case surface. Pull test results are shown in Table 3. All pull test results were above the KSC minimum requirement of 50 psi. One pull test failure mode was 100 percent cohesive in the cork and another was a combination of cohesive cork failure and adhesive failure between the cork and tensile button. A third pull test failure was a combination of cohesive cork failure and adhesive failure between the cork and the case/paint. The pull test results showed that pressure on the cork may not have been adequate to result in a consistent bondline.

It was not possible to pull test the aft cork band because the bondline is angled relative to the cork outside surface.

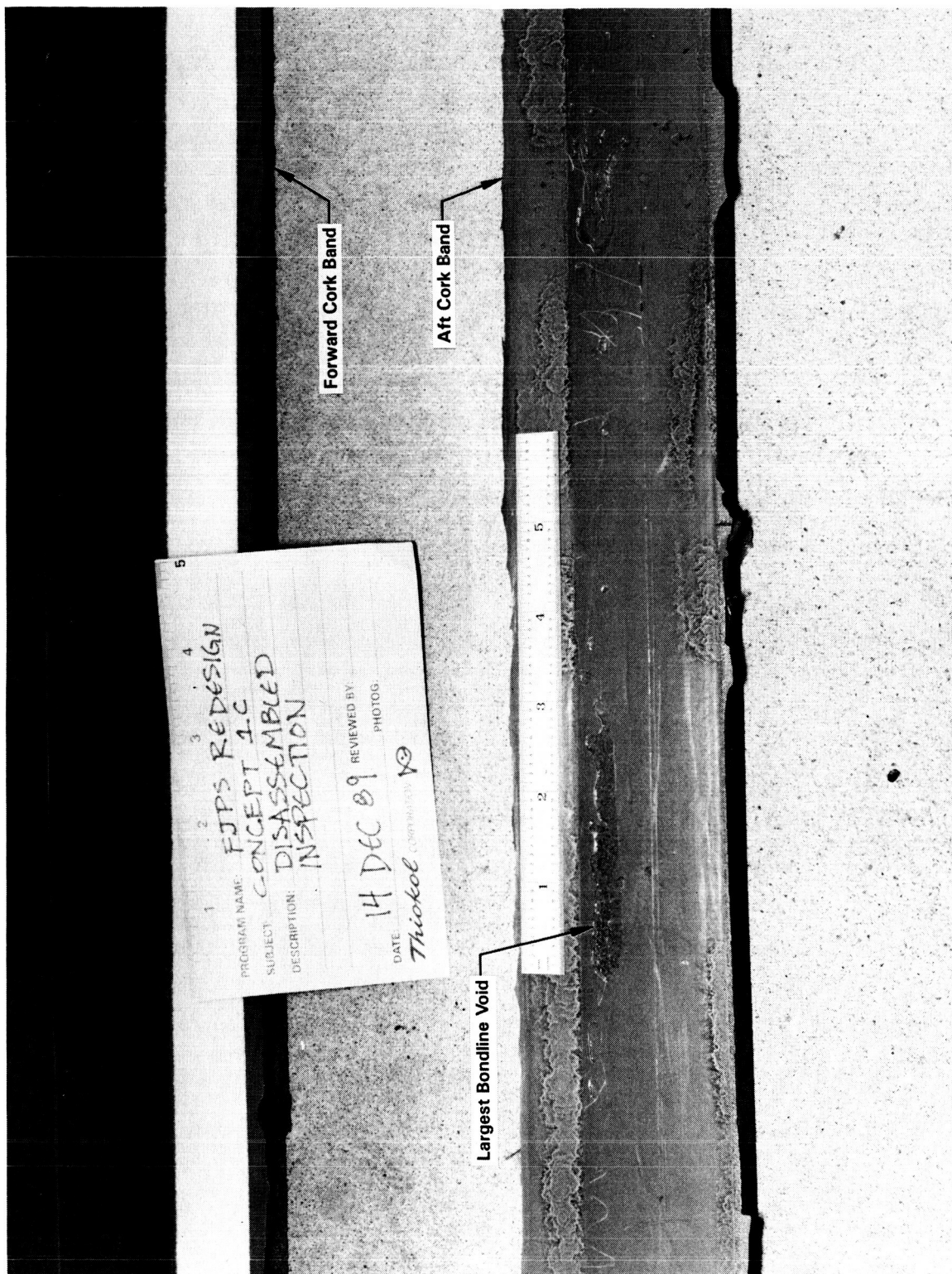


Figure 8. Concept 1C--EA 934NA Adhesive Bondlines

Table 3. FJPS Concepts 1 and 1C—Pull Test Data

FJPS Configuration	Adhesive	Number	Case Location (deg)	Ultimate Load (lb)	Ultimate Stress (psi)	Failure Mode (%)		
						Cohesive Cork	Adhesive Test Button	Adhesive Pin Retainer Band
Concept 1— Aft Cork Band (nominal tolerance over the pin retainer band)	EA 934NA (STW4-3218)	1	85	125	103	10		90
		2	75	90	74	25	75	90
		3	70	80	66	10		
		4	62	90	74	20	80	
		5		140	167	95	5	
		6		150	125	98	2	
		7		155	129	95	5	
	EA 934NA (STW4-3218) With Cab-O-Sil Filler (2.5% by weight)	8	20	95	79	20	80	
		9	15	110	91	75	25	
		10	15	160	132	100		
		11	2	95	79	20	80	
		12		140	167	75	25	
		13		155	129	100		
		14		155	129	100		
	EC 2216 with Cab-O-Sil filler (3.0% by weight)	15	170	160	132	100		
		16	160	165	136	100		
Concept 1C— Forward Cork Band	EA 934NA (STW4-3218)	17	355	180	149	50		50
		18	300	140	116	100		
		19	270	140	116	20	80	

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6.3 CONCEPT 1 AFT CORK BAND INSTALLATION EVALUATION

Installation. This installation consisted of sections of the Concept 1 aft cork band only. The cork band was machined to fit against the pin retainer band (nominal tolerances). Half of the case bondline surface was covered with Teflon[®] tape for each of the three adhesives evaluated (Figure 4). The preparation and installation procedures were similar to those for the Concept 1C aft cork band installation.

The three adhesives evaluated were: EA 934NA adhesive, EA 934NA adhesive with Cab-O-Sil filler (2.5 percent by weight), and EC 2216 adhesive with Cab-O-Sil filler (3.0 percent by weight). Cab-O-Sil hardener was added and mixed into the adhesives after the adhesive resin and hardener were thoroughly mixed. Cab-O-Sil was weighed to ensure exact formulations.

Cab-O-Sil was added to the EA 934NA adhesive because in previous testing under ETP-0600 this adhesive drained from the aft cork band butt joints during cure (the aft cork band sections were machined for a worst-case tolerance over the pin retainer band for testing under ETP-0600). EC 2216 adhesive was evaluated to compare its processing ability to EA 934NA adhesive. The potlife of EC 2216 adhesive is 90 min, and the potlife of EA 934NA adhesive varies with temperature: at 60°F, potlife is 98 min; at 90°F, potlife is 46 min (STW7-3631 Revision B). At 70°F, the cure time of EC 2216 adhesive is 10 hr (TWR-18104); the cure time of EA 934NA adhesive is 8 hr (at KSC).

Personnel applying the adhesives preferred the workability of the EC 2216 adhesive with Cab-O-Sil best, then the EA 934NA adhesive with Cab-O-Sil, and lastly the EA 934NA adhesive without filler. All cork was installed and the two steel strapping bands were tightened within the potlife of each adhesive. Adhesive squeezeout occurred across the entire cork/case bondline for each adhesive (Figure 9). Test bay ambient temperature varied between 60° and 70°F during the installation.

Inspection. Removal of the cork sections that were installed over the Teflon[®] tape revealed bubbles (approximately five bubbles across 1 ft of cork) in the cured EC 2216 adhesive (Figure 10). The largest of these bubbles was 1.5 by 0.25 inches. The EA 934NA adhesive with Cab-O-Sil bondline had a few small pits. The EA 934NA adhesive bondline had no visible voids and was thinner than the other two adhesive bondlines.

The presence of cork/case adhesive bondline voids, bubbles, and pits could have been caused by separations between the cork and case during the installation process. After the adhesive-coated cork was initially fitted against the case, it may have separated at the cork section ends and other areas prior to the tightening of the steel strapping bands.

Pull Testing. Five days after the cork installation, pull testing was performed to determine the bondline integrity for cork sections that were installed directly to the case (Figure 11). Pull tests



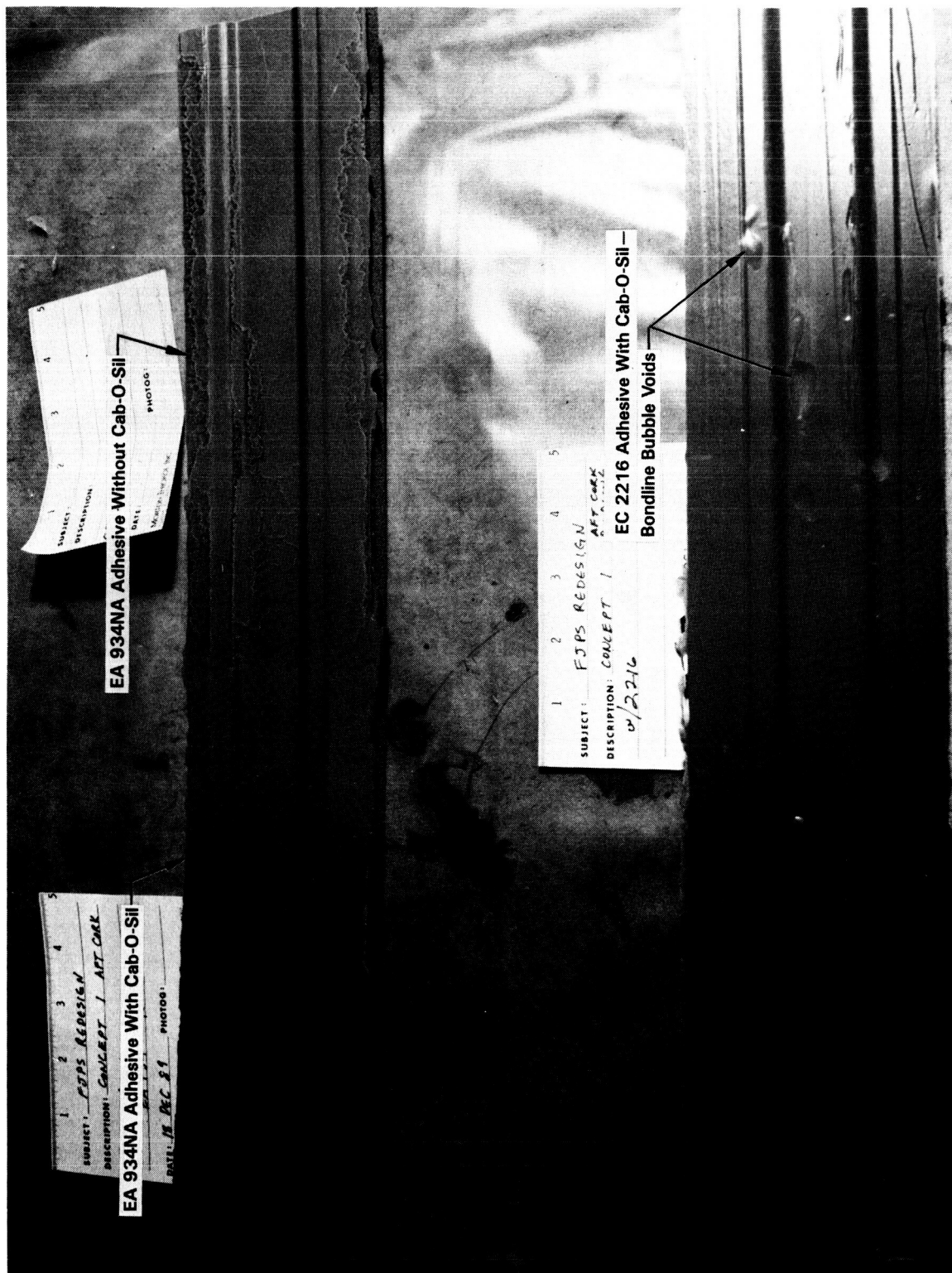


Figure 10. Concept 1 Aft Cork Band--Adhesive Bondline Comparison



Figure 11. Concept 1 Aft Cork Band--Typical Pull Test

for each adhesive were performed; the results are listed in Table 3. Two of the seven pull tests performed over the EA 934NA adhesive failed at the cork/case adhesive bondline, indicating that the pin retainer band surface may have been contaminated during installation. Cohesive cork failures in the other pull tests indicate adequate adhesion for each adhesive.

APPLICABLE DOCUMENTS

<u>Document No.</u>	<u>Title</u>
ETP-0600	Thiokol/Wasatch FJPS Short Stack Demonstration Test Plan
ETP-0620	Evaluation of the New FJPS Closeout Concept Test Plan
STW4-2700	Cork, Sheet
STW5-3183	Ablation Compound, Cork-Filled (K5NA)
STW4-3218	Epoxy Resin Adhesive, Nonasbestos, Structural Bonding (EA 934NA)
STW7-3260	Ablation Compound, Cork-Filled, Application and Cure of
STW7-3631	Cork Insulation Installation, Process Finalization
TWR-50018	Thermal Analysis/Verification of SRM JPS Redesign Concepts
TWR-50253	JPS Closeout Design Review
<u>Drawing No.</u>	<u>Title</u>
7U76603	Short Stack Assembly, FJPS
TUL-16825	FJPS Vertical Demonstration

APPENDIX

Radial Force Applied to Cork During Bonding With Steel Strapping Bands

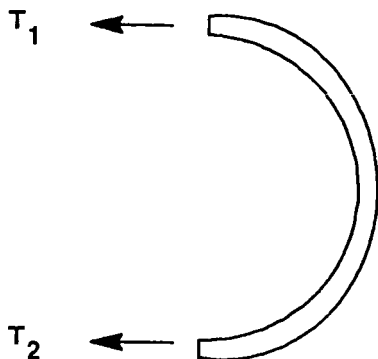
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Radial force applied to cork during bonding with steel strapping bands

Assuming radial force will be at a minimum 180-deg from the tensioning tool and tensioning tool force = 700 lb

Consider a 180-deg section of one steel strapping band



T_1 location near tensioning tool

T_2 180 deg from tensioning tool

$T_1 > T_2$

$$\frac{T_1}{T_2} = e^{f\theta}$$

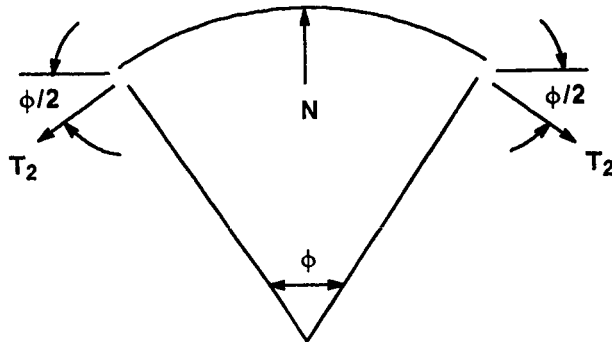
From: *Fundamentals of Machine Component Design* (pg 581)
by Robert C. Juvinal, John Wiley and Sons, 1983

Where f = coefficient of friction for Teflon/steel
 $f = 0.04$, *Mark's Standard Handbook for Mechanical Engineers*, Baumiester, Avallone, Baumiester, 1979

θ = angle of contact
= 180 deg = π radians

$$T_2 = \frac{T_1}{e^{f\theta}} = \frac{700 \text{ lb}}{e^{(0.04)\pi}} = 617 \text{ lb, tension in band 180 deg from tensioning tool}$$

Radial force: consider a free body diagram of a 1-deg section at 180-deg



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Assume band tension does not vary significantly over a 1-deg section

$$\phi = 1 \text{ deg} = 0.1745 \text{ rad}$$

$$\Sigma F_y = 0 = N - 2T_2 (\sin \frac{\phi}{2})$$

$$N = 2T_2 (\sin \frac{\phi}{2}) = 2(617) (\sin \frac{0.1745 \text{ rad}}{2})$$

$N = 10.81 \text{ lb}$, radial force applied by band, 180-deg from tensioning tool

At tensioning tool:

$$N = 2(700 \text{ lb}) (\sin \frac{0.1745 \text{ rad}}{2})$$

$N = 12.22 \text{ lb}$, radial force applied by band, at tensioning tool

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